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# **Technical Report ARPAD-TR-90001**

# THE FEASIBILITY OF DETECTING CORROSION IN ELECTRIC FUZES USING THE THERMAL TRANSIENT TECHNIQUE

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**April 1990** 



# U.S. ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

Product Assurance Directorate Picatinny Arsenal, New Jersey

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### INTRODUCTION

The object of this experiment was to determine if the thermal transient test can be used to detect corrosion on the bridgewire in an electric fuze or electroexplosive device (EED) (fig. 1). The fuzes are used to set self-destruct times in the following mines: M74, M75, BLU-92/B (fig. 2). When the mines are exposed to high humidity the bridgewire inside the fuze is susceptible to corrosion. An open (corroded) fuze may initiate the wrong self-destruct time which in turn will create a hazardous condition for friendly troops. Two examples of severe corrosion of the bridgewire in a fuze are shown in figures 3 and 4. These photographs were taken by a scanning electron microscope.

The current method for detecting corrosion in a fuze is measuring the cold resistance of the bridgewire. A high resistance reading indicates evidence of corrosion. It will be determined if the thermal transient test can be used as an alternative method.

#### **THEORY**

The thermal transient test is a nondestructive examination technique for inspection of the critical bridgewire interface. The test allows one to see inside the fuze non-destructively and determine if certain failure conditions or abnormalities are present.

Application of a current to a hot bridgewire type fuze causes the bridgewire temperature to increase due to dissipation of energy in the bridgewire. The temperature rise is accompanied by a corresponding increase in the resistance of the bridgewire material having a reasonable temperature coefficient of resistivity (TCR). By controlling the amplitude and duration of the current pulse the fuze will return to ambient temperature with no discernible permanent change at cessation of the pulse. The pulse magnitude is selected so that stress thermal characteristics become responsive. Pulse duration is chosen to produce interface thermal equilibrium. The rate at which the bridgewire changes, and the maximum value of the change, are determined by the interface characteristics. The signals generated by the changes are displayed on an oscilloscope for observation and analysis.

A fuze will generate a thermal response curve whose specific shape is controlled by the thermal capacity and thermal resistance inherent in the design of the fuze. A normal heating curve is always smooth and continuous. A typical electrothermal response of a fuze under test is illustrated in figure 5. The horizontal axis is a time base. The vertical axis represents the voltage developed across the bridgewire terminals.

Thermal response curves generated by the thermal transient test graphically describe the electrothermal character of the bridgewire interface under examination. The normal heating curve can be seriously degraded by interface faults; such as, corrosion, defective bridgewire welds, and other irregularities. A normal curve is shown in figure 6

and an abnormal curve due to corrosion is shown in figure 7. Defective mechanical fuzing of the bridgewire and posts, corrosion of the bridgewire and weld joints combine to generate a wide variety of erratic responses.

## **Thermal Transient Apparatus**

Applying current to a bridgewire produces a rise in bridgewire temperature. The resistance of the bridgewire increases as does the voltage drop across it.

The apparatus used for measuring the thermal characteristics of electroexplosive devices (EED) was designed by Pasadena Scientific Industries (fig. 8).

The machine applies a balancing current to the device under test. Essentially a Wheatstone bridge is balanced. This is a low current pulse (10 mA was used for this experiment) to balance the Wheatstone bridge by obtaining a null or zero voltage on the oscilloscope. The variable resistor will match the resistance of the device under test.

A test current pulse can now be applied to the bridge and the voltage drop across the bridge can now be measured on the oscilloscope. This voltage drop will be the voltage drop across the device under test.

Using a storage oscilloscope one can capture the test pulse as a voltage drop. The test pulse for a normal fuze is the bridge is shown in figure 9. Observing higher frequencies, the test pulse can be seen as the bridgewire (in the fuze) heats up and its resistance changes (fig. 9). Sweeping for a still shorter time, one can observe the initial part of the pulse as the voltage drop increases across the fuze. (fig. 9).

A balancing current of 10 milliamperes was used. The pulse duration was 15 milliseconds. This pulse was repeated approximately once every second. A normal thermal curve for an electric fuze as the device under test is shown in figure 6. Note the short spike in the initial part of the curve. This is caused by the reactance of the machine bridge and other components as the test pulse is applied. The beginning of the trace was considered to be voltage = 0, time = 0.

# **Digital Storage Oscilloscope**

The Nicolet Model 905 was used for the display and storage of the thermal measurements. The trigger output from the thermal transient apparatus was connected to channel B of the oscilloscope for amplification. Channel A was used for the voltage signal from the bridge. In the millisecond range the test pulse could be observed and in the microsecond range the thermal response could be observed.

# Machine settings were:

Channel A: 100 mV full scale D.C. coupling

Channel B: 200 mV full scale D.C. coupling

Sweep: millisecond and microsecond range

Trigger: Channel B

#### **Procedure**

1. Perform thermal transient test on 25 electric fuzes. These should be brand new parts. This includes a measure of cold resistance with an ohmmeter.

- 2. Subject 15 of the 25 to an extreme environment of high humidity and high temperature.
  - 3. Thermal transient measurement on all 25 fuzes.
- 4. Continue 24-hour periods of extreme conditions on the test group of 15 fuzes. Take thermal measurements of the entire set of 25 after each period.
- 5. Periods for this experiment were: 0 hours humidity exposure, 24, 48, 72, 96, 168, and 192 hours.
- 6. Compare thermal curves of fuzes subjected to humidity to the original thermal curves of 0 hours humidity exposure.
- 7. Correlate thermal measurements to the degree of corrosion of the fuzes. This includes inspection of the bridgewire and header cap assembly under an electron microscope.

The first part of each test was measure of the cold resistance of the fuze. This was done with an ohmmeter. The maximum current through the fuze from the meter was approximately 2 milliamperes. The resistance would increase if the ohmmeter was held on the fuze for too long. This presented some error, plus or minus 0.3 ohms at the most.

The fuze was then connected to the thermal transient machine input through two short clip connectors, approximately one inch in length. The resistance of the cables did not appear to affect the signal from the bridge and was therefore considered nominal.

The machine was balanced by obtaining a flat trace (zero voltage drop) on the oscilloscope. This was done with the 10 mA balancing current. The thermal test was conducted using the 25 mA pulse. The curves were stored on disk. Measurements taken were maximum voltage (amplitude), half the maximum voltage, and time to reach half the maximum voltage.

Fifteen fuzes wre subjected to a high humidity, high temperature environment. The environment was 100 percent humidity at a temperature of 150°F. After 24 hours in this humid environment the thermal test was repeated with the same settings (test current = 25 mA for 15 ms) on the thermal transient machine. The only different setting was the balance resistance which required adjustment for each fuze in order to balance out the cold resistance.

After a fuze was subjected to a humid environment, the time to reach half the maximum voltage was subtracted from the respective time from test 1 (the time to reach half the maximum voltage for that fuze with no humidity exposure). This difference (t2-t1 for example) represents the difference in rise time between two thermal tests for the test group (fuzes 1 through 15). The control group (fuzes 16 through 25) also had a difference in rise (t2-t1) but neither t2 nor t1 represents the fuze subjected to any humidity. These fuzes were in a dry place at room temperature for all tests. The difference in rise time for this group was then considered the variation in measurement due the thermal transient test set. Averaging the differences for the control group a machine error was obtained. This was then subtracted from the test group rise time differences (t2-t1-average control group difference). This quantity was then considered the difference in rise time between two thermal tests and is corrected for machine error. This was done for tests 2 through tests 7.

After all thermal tests were done the fuzes were examined under optical microscope to observe the header seal on the fuze. The head was then cut open and they were examined under a scanning electron microscope. This work resulted in exceptional pictures of the fuze bridgewire and weld joints of all 25 fuzes.

#### DISCUSSION

Voltage and time measurements were taken from each test. Data are tabulated in appendix A with the following explanations:

Ro is the cold resistance of the fuze as measured on an ohmmeter.

Vmax is the maximum amplitude the voltage across the fuze reached. When no Vmax is given in the table Vmax is simply the voltage V(t). All voltages are d.c. and in millivolts.

V(t) is the voltage at one point on the thermal curve and was usually taken at Vmax or near it.

t(1/2) is the time in microseconds at which the voltage drop is V(t) divided by two.

T2,T3...-T1 represents the rise time t(1/2) from test 1 (0 hours humidity exposure) subtracted from t(1/2) of another test.

T2,T3...-T1-avg. ctrl. diff. represents t(1/2) of test 1 subtracted from t(1/2) another test. Subtracted from this quantity is the average difference in rise times of the control group (fuzes 16 through 25).

Where data is missing in the tables the fuze was pulled out either to be examined under the electron microscope, or the fuze was blown, or the resistance had increased and it could not be tested by the thermal transient machine.

Also computed was the coefficient B from equation 2 (fig. 5) for each fuze from each of the seven tests. This is tabulated in appendix B.

The maximum voltage drop for all 25 fuzes on the first test is shown on graph 1 (app C). Note the large spread or variation between the fuzes. The amplitude of the voltage will vary between 33 mV to 92 mV depending on the fuze. Again, the current was the same for all the tests. The maximum voltage reached for the other six thermal tests is shown on graphs C-2 through C-7 (app C). Note that the voltages for the test group (fuzes 1 through 15 on the horizontal axis) and the voltages for the control group (fuzes 16 through 25) remain approximately the same from test to test. The graph is the same shape for each test. This indicates that the variance in voltage readings is due to the fuzes and not to the thermal test set.

The time to reach V(t)/2 or approximately half the maximum voltage for each test is shown on graphs C-8 thorugh C-14 (app C). Here again, the times are scattered from fuze to fuze but the graph takes the same shape for each test. Here, however, the rise times for the test group (fuzes 1 through 15) start to increase as the fuzes are exposed to more humidity. Note that in each test in the control group (fuzes 16 through 25) the rise time never goes above 500 microseconds. Comparing graphs C-8 and C-9 (app C), one can see that fuze 3 has increased from a rise time of 230  $\mu S$  (0 hours humidity) to a rise time of 800  $\mu S$  after just 24 hours of high humidity and high temperature exposure.

The difference in rise time after the test fuzes were in high humidity is shown in graph C-15 (app C). This graph and graphs C-16 through C-20 are corrected for machine error by subtracting out the average difference in the control group between the two tests from the test group rise times. These graphs show that on the average the test group (fuzes 1 through 15) showed a greater change in rise time than the control group (fuzes 16 through 25). Some fuzes in the test group did not show a significant change in rise time compared to test 1. Note also that some changes in rise time of the test group were equal to the variance in rise time of the control group.

The difference in rise time between tests 2 through 7 and test 1 should be zero (ideally) for the control group. The control group should not vary from test to test as the fuzes 16 through 25 were not subjected to any stress between test. The difference in rise time measurements here must then be a variation in test conditions or the machine error (or actual deterioration of the control fuzes). Subtracting the average of the rise time differences from all of the rise time differences was considered a correcting factor in test measurements. Both the difference in rise time and the corrected difference are shown in the tabulated data of appendix A.

The next part of the expreiment was to fit the curve to equation 2 (fig. 5) which was done by calculating the coefficient "B". This is inversely proportional to the rise time. These coefficients are tabulated in appendix B. The calculated coefficients with the coefficient for each test plotted with test 1 coefficients are summarized on graphs C-1 through C-6 (app C). For example, in graph 22 the square points represent test 3. Note the coefficients are lower in the test group of test 3 than test 1. The coefficients remain generally stable for the control group (fuzes 16 through 25).

The coefficients for six thermal tests are shown on bar graph B-6 (app B). Test 6 of 168 humidity exposures was omitted from the plot due to the plotting program. The leftmost bar represents the coefficient B from test 1; 0 hours humidity exposure. One can see the bar height decreses as the test increases for fuzes 1 through 15, the test group. The rightmost bar (test 7) is always lower than the leftmost (test 1). In general, the B coefficient decreased as the fuzes were subjected to more humidity.

Lastly, the fuzes were examined under optical and scanning electron microscope. The results showed minor to severe corrosion for all 25 fuzes. The test fuzes (1 through 15) had severe corrosion, but the control group also showed corrosion that was considered severe. Typical corrosion is shown in figures 3 and 4.

## CONCLUSION

The purpose of this experime it was to determine if the thermal transient technique is a feasible way to detect corrosion of a fuze bridgewire. Referring to graph C-15 (app C) one can see a difference between the rise time of a fuze after exposure to a humid environment (fuzes 1 through 15) and the rise time of a fuze that was not exposed to humid conditions. The results of test 2, 24 hours humidity exposure in appendix C show an average rise time of 332 microseconds for the control group while the average rise time for the test group was 400 microseconds. Clearly there was a difference between the test group and control group measured on the thermal transient apparatus. There was, however, a large standard deviation in all measurements (large scatter of readings). This could be explained by assuming faulty seals on the fuzes, thereby compromising fuze integrity. The consistency of these readings ruled out that machine error and the variance was taken to be from the fuzes themselves. Referring to graph C-15 (app C) again, one can see that the difference in rise time from test 1 for the test group can be the same order of magnitude as the control group. Within a test the variance in measurements can account for the two groups showing the same rise time difference from test 1.

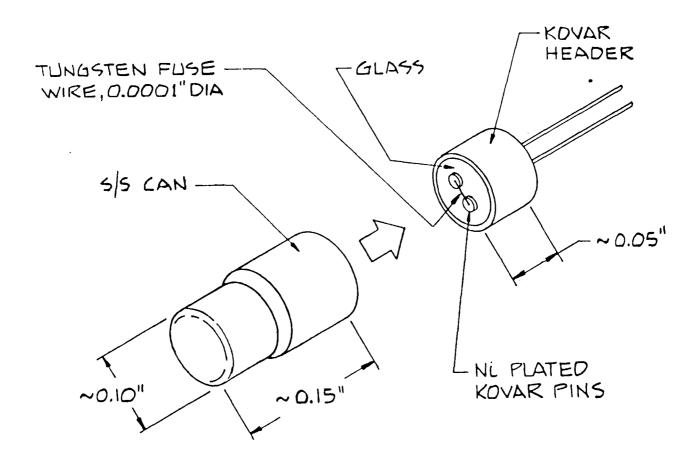
Again, the machine error was considered the average difference of a control group from test 1 because there should not have been a difference for this group. Referring to graphs C-15 through C-20 (app C) one can see that the control group's rise time difference from test 1 varies from test to test. The difference, however, was generally stable. For example, control fuze 20 has a difference from test 1 of +62, +23, +44, +26, +29, and +22  $\mu S$  for test 2 through 7, respectively. This is a plus or minus 20  $\mu S$  change from test to test. The change is most probably experimental error in each thermal test. This error could include balancing conditions of each test, contact of wire clips and fuze leads (oxidation of the leads also), and temperature changes in the lab which would affect the heat dissipation at the fuze bridgewire.

Another example of a corroded bridgewire is shown in figure 10 (fuze 9 from the test group after 192 hours of humidity exposure). The bridgewire of fuze 18 from the control group is shown in figure 11. Note corrosion along the wire and how the wire is bent out of the weld to the fuze lead (lower left corner). There were similar defects in all 25 fuzes from the results of the electron microscope evaluation. The control group fuzes showed minor to severe corrosion as did the test group. This can account for the large variance in measurements between fuzes as each fuze possessed a unique degree of corrosion or weld defect. While the corrosion on test group fuzes was expected, lifted bridgewire at the weld was not.

On the average though, the thermal rise time increased for the test group as humidity exposure increased (app C graphs C-15 through C-20). Fuzes 1 through 15, on the average, can be seen to increase as the test increases. While some differences from the test group are the same order of magnitude as the control group, there was generally more of a change in rise time in the test group then the control group.

The results of the electron microscope inspection showed that all of the fuzes possessed some degree of corrosion as given. The results of the thermal measurements and humidity exposure represent the thermal transient apparatus detecting an even greater degree of corrosion while showing a large variance between measurements from each fuze.

# THE TUNGSTEN FUSE



After wire attachment and inspection, the S/S can is crimped over end of header and header to can interface sealed with a potting material.

Figure 1. Electric fuze

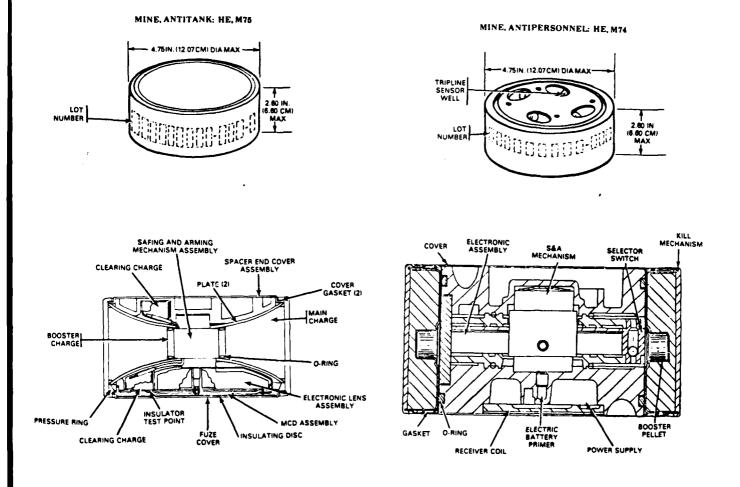


Figure 2. Two mines which use the electric fuze



Figure 3. Severe corrosion along the bridgewire

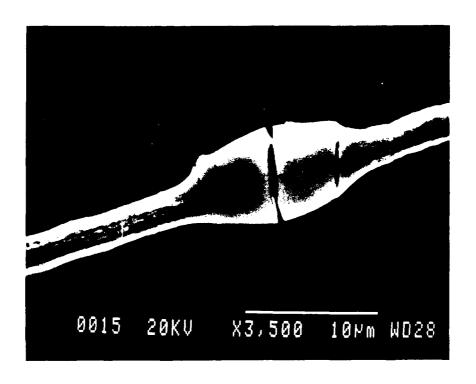
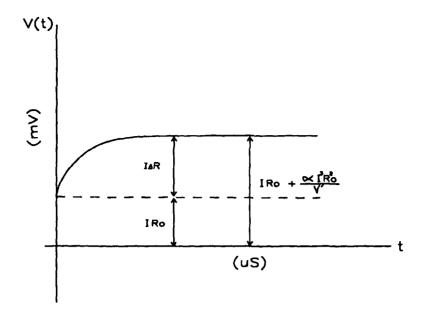


Figure 4. Close-up of corroded bridgewire



$$V(t) = I Ro \left[ 1 + \frac{\propto I^2 Ro}{V'} \left( 1 - e^{-\frac{V'}{C_p}} \right) \right]$$

$$V' = V - \propto I^2 Ro \quad \text{and} \quad V' = \frac{C_p}{V} = \text{time constant}$$
(1)

Where:

V = Thermal Conductance

I = Test Current

Ro - Cold Resistance

C<sub>p</sub> = Thermal Capacitance

Equation 1 can be rewritten:

$$V'(t) = V_{max} \left( 1 - e^{-Bt} \right)$$

$$Where: V'(t) = V(t) - IRo$$

$$B = \frac{V'}{C_p}$$

$$V_{max} = \frac{\propto I^3 Ro^2}{V'}$$

Solving (2) for B:

$$B = \frac{-1}{t} * Ln \left(1 - \frac{V'(t)}{Vmax}\right)$$

Figure 5. Voltage drop across fuze

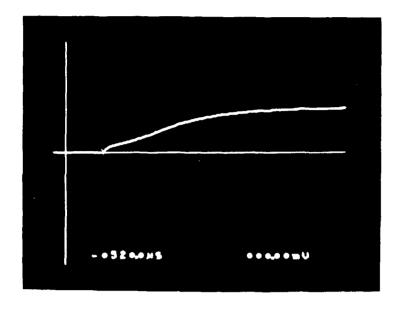


Figure 6. A normal heating curve

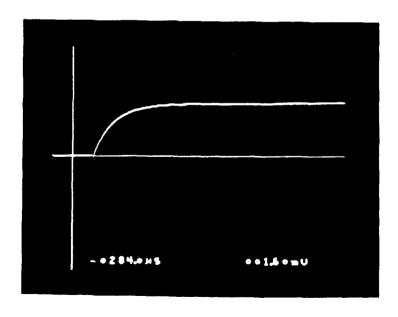
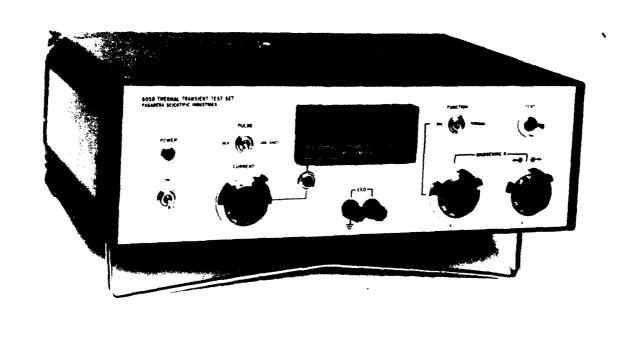
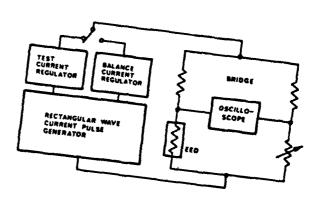


Figure 7. An abnormal heating curve







Circuit configuration

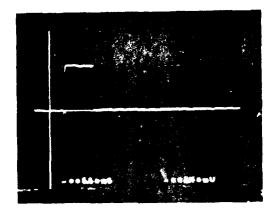
Figure 8. Thermal transient test equipment

### THERMAL TRANSIENT TEST SET - MODEL 605B

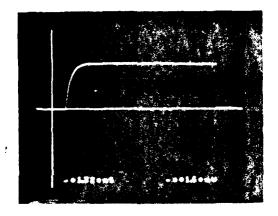
## SPECIFICATIONS

- \* BRIDGEWIRE RESISTANCE RANGE: 0.10 to 10.50 ohms.
- \* TEST CURRENT: 10 to 2,000 milliamperes (adjustable by 10-turn front panel control).
- \* BRIDGE BALANCE CURRENT: 10 milliamperes (internally adjustable from 5 to 15 milliamperes).
  - TEST CURRENT INDICATOR: 3½ digit panel meter (0 to 1999 milliamperes).
  - BRIDGEWIRE RESISTANCE READOUT: Two 10-turn dials.
  - CURRENT PULSE MODES: Repetitive or one-shot (selectable by front panel switch).
  - CURRENT PULSE DURATION: 10 to 70 milliseconds (adjustable by internal control).
  - CURRENT PULSE REPETITION RATE: 2.5 to 9.0 pulses per second (adjustable by internal control).
  - BRIDGE BALANCE STATUS INDICATOR: Two (2) light emitting diodes (LED's).
  - INPUT POWER: 105 125V, 50-60Hz, 75 watts (max).
  - TEMPERATURE: Operating: 0°C to +50°C Storage: -40°C to +70°C
  - COOLING: Convection.
  - DIMENSIONS: 16.88"W x 5.25"H x 12.70"D (bench mount). 19.00"W x 5.25"H x 12.70"D (rack mount).
  - WEIGHT: 22.5 lbs (approx) net; 36.0 lbs (approx) shipping
  - ACCESSORIES SUPPLIED: AC power cord; coaxial cable assemblies; Reference Bridgewire RB101; cabinet tilt stand; Installation and Operating Manuals.
- \* NOTE: The 605B has a single-ended output and is designed for use with a user-supplied oscilloscope with lmv/cm vertical deflection sensitivity.

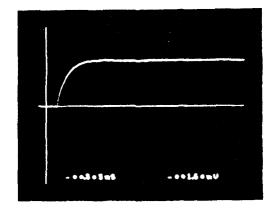
Figure 8. Continued



 $20~\mu S$  sweep



 $10~\mu S$  sweep



2 μS sweep

Figure 9. Test pulse

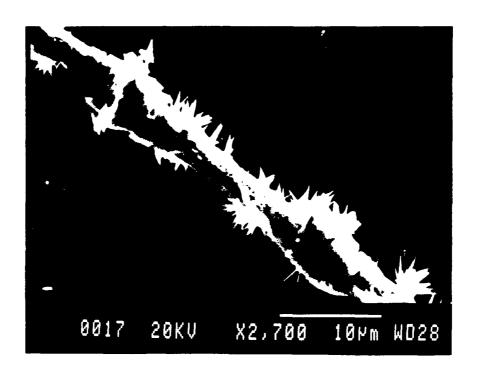
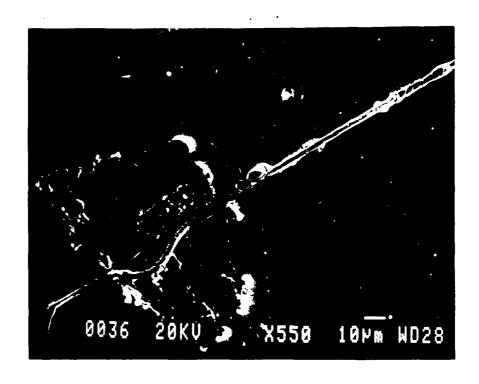


Figure 10. Fuze 9 test group



Fuze 11. Fuze 18 control group

# Appendix A

Tabulated Thermal Data

			Test 1	0 Hours	Humidity	
Fuss#		Ro	Vmax	V(t)	V(t)/2	t 1/2
	1	9.5	78.4	77.6	38.8	337
	2	8		32.8	16.4	263
	3	9.5		49.6	24.8	230
	4	8.7		63.2	31.6	347
	5	9.5	91.2	90.4	45.2	359
	6	9.9		49.6	24.8	198
	7	10	52.8	52	26	192
	8	9.1		42.4	21.2	181
	9	9.6		89.6	44.8	418
	10	8.4		56.8	28.4	371
	11	9.4		88.8	44.4	413
	12	9.4		64.8	32.4	315
	13	9.3	43.2	41.6	20.8	146
	14	8.3		61.6	30.8	341
	15	9.5	40.8	40	20	186
	16	9.5	46.4	44.8	22.4	210
	17	9.3	80	78.4	39.2	414
	18	9.2	48	47.2	23.6	275
	19	8.6		66.4	33.2	383
	20	9	78.4	76.8	38.4	374
	21	9.1		56.8	28.4	277
	22	8.9		44	22	235
	23	9.1	32.8	32	16	168
	24	9.2	85.6	84	42	327
	25	9.3	89.6	84.8	42.4	374

	TES	Т 2 24 Н	OURS Humidit	y		
fuss # r	0 V m				track	avg
1	9.7		4.8 42.4		1	3
2	8.1	3	2.8 16.4	300	2	
3	9.8		9.2 19.6		3	
4	8.8	64.8 6	3.2 31.6		4	
5	9.8	99.2 9	7.6 48.8	486	5	
6	9.9	5	1.2 25.6		6	
7	10.1	5	0.4 25.2	257	7	
8	9.3	4	6.4 23.2	206	8	
9	9.7	99.2 9	6.8 48.4	503	1	
10	8.5	63.2 6	2.4 31.2	450	2	
11	9.7	96.8 9	4.4 47.2	544	3	
12	9.9	65.6	64 32		4	
13	9.5	44.6 4	0.8 20.4		5	
14	8.8	63.2 6	2.4 31.2	538	6	avg.Samp.
15	9.9	5	3.6 26.8	141	7	400.4666
16	9.5	4	9.6 24.8	218	8	
17	9.7	87.2 8	6.4 43.2	426	1	
18	9.5	4	7.2 23.6	305	2	
19	9.1	7	0.4 35.2	428	3	
20	9	80.8	80 40	436	4	
21	9.2	5	5.2 27.6	257	5	
22	9.2	4	4.8 22.4	202	6	
23			C	)	7	
24	9.4	8	8.8 44.4	343		avg.Ctr.
25	9.6		96 48	374	8	332.1111

	Test 2	Diff. fro	om Test 1
t2-t1=t		Fuss #	t-avg.
39		1	25.667
37		2	23.667
569		3	555.667
165		4	151.667
127		5	113.667
48		6	34.667
65		7	51.667
25		8	11.667
85		9	71.667
79		10	65.667
131		11	
117			117.667
		12	103.667
71		13	57.667
197		14	183.667
-45		15	-58.333
8		16	8
12		17	12
30		18	30
45		19	45
62		20	62
-20		21	-20
-33	avg.Dff		-33
	13.3333	3 23	0
16	std.Ctr		16
0	28.1306		0

			TEST 3	48 Hours	Humidity	•	
fuss#	Ro		Vmax	V(t)	V(t)/2	t(1/2)	Avg $t(1/2)$
	1	10.1	88	87.2	43.6	467	
	2	8.3		33.6	16.8	422	
	1 2 3						
	4 5	10.6	92.8	87.2	43.6	577	
	5	10.2		105.6	52.8	462	
	6	10.5		44	22	236	
	7	10.7		40.8	20.4	221	
	8 9	9.6		48	24	208	
	9	9.9	100	98.4	49.2	467	
	10	8.8	66.4	64	32	463	
	11	11.2	118.4	113.6	56.8	551	
	12	10.1	68	67.2	33.6	436	
	13	10.1	41.6	40	20	192	
	14	10.1	88	80.8	40.4	623	avg Samp
	15 ·	10.1	41.6	40.8	20.4		393.7142
	16	9.5		53.6	26.8	193	
	17	9.4	88	87.2	43.6	407	
	18	9.3		51.1	25.55	252	
	19	8.8		70.4	35.2	370	
	20	9.2		84	42	397	
	21	9.3	56.8	56	28	248	
	22	9.1	45.6	44.8	22.4	222	
	23						
	24	9.4		88	44	362	avg Ctrl
	25	9.6	96.8	94.4	47.2	398	316.5555

	Test 3 Di			1	
Fuse#	t3-t1=t	avg diff.	•		t-avg.dif.
1	130				132.222
2	159				161.222
3					
4	230				232.222
5	103				105.222
6	38				40.222
7	29				31.222
8	27				29.222
9	49				51.222
10	92				94.222
11	138				140.222
12	121				123.222
13	46				48.222
14	282				284.222
15	1				3.222
16	-17				-17
17	-7				-7
18	-23				-23
19	-13				-13
20	23	ctr dif			23
21	-29	-2.22222			-29
22	-13	std.			-13
23		21.93818			
24	35	std(n-1)			35
25	24	23.269			24

fuss#	r0 1 2 3	10.4	TEST 4 Vmax 88.8 34.4	72 Hours V(t) 88 32.8	Humidity v(t)/2 44 16.4	t(1/2) 392 289	avg
	4	11.7	1	unbalance	0		
		10.3	107	104	52	469	
	5 6 7	11	44	43.2	21.6	269	
	7	11.2		38.4	19.2	314	
	8	10		40	20	225	
	9	10.4	96	94.4	47.2	588	
	10	9	67.2	65.6	32.8	508	
	11				0		
	12	10.2	68.8	68	34	455	
	13	10.3		41.6	20.8	193	
	14	15.9	ι	unbalance	0		avg.Samp
	15	10		42.4	21.2	219	356.4545
	16	9.4	51.2	50.4	25.2	185	
	17	9.3	88.8	87.2	43.6	403	
	18	9.2		51.2	25.6	248	
	19	8.6	72	70.4	35.2	408	
	20	9.4	87	86.4	43.2	418	
	21	9.3	55.2	54.4	27.2	236	
	22	9.3		43.2	21.6	196	
	23						
	24	9.6	82.4	81.6	40.8	334	avg.Ctrl.
	25	9.9		92	46		313.6666

		Test 4 Di	ff. from '	Test 1	
fuss	#	t4-t1=t .			Ctrl
		55	J	60.1Ĭ1	
	2	26		31.111	
	3				
	1 2 3 4				
	5	110		115.111	
	6	71		76.111	
	7	122		127.111	
	8	44		49.111	
	9	170		175.111	
	10	137		142.111	
	11				
	12	140		145.111	
	13	47		52.111	
	14				
	15	33		38.111	
	16	-25		-25	
	17	-11		-11	
	18	-27		-27	
	19	25		25	
	20	44		44	
	21	-41		-41	
	22	-39	Avg Ctrl	-39	
	23		-5.11111		
	24	7		7	
	25	21		21	

_		TEST 5	96 Hours	Humidity	7	
fuss#	Ro	Vmax	V(t)	V(t)/2	t(1/2)	Ava t1/2
	10.4	92.8	91.2	45.6	424	3
	2 8.6	28.8	28	14	735	
	3 Cut-up			0		
	4 13.2 5 10.3			0		
	5 10.3	112	107.2	53.6	641	
	6 10.6 7 11		44.8	22.4	240	
			40	20	246	
	8 9.8		42.4		223	
	9 10.3	107.2	105.6		482	
1	0 9.2	66.4	60.8		948	
1	1 Cut-up			0		
1	2 10.3	67.2	65.6	32.8	482	
1		42.4	41.6		350	
	4 Blown			0		avg t1/2
1		43.2	41.6	20.8		453.5454
1	6 9.3		49.6	24.8	196	
1			84	42	403	
1		48	47.2	23.6	235	
1	9 8.5		69.6		381	
2			83.2			
2	1 9.3		55.2	27.6	239	
2:			44	22		avg ctrl.
	3 Cut-up			0		312.8888
2	4 9.7		86.4	43.2	340	std.ctrl.
2	5 9.6	92.8	92	46		85.30135

•	Test 5 Di	ff. from Test	1
		avg diff.	t-avg.dif.
1	87	<b>J</b>	92.88
2	472		477.88
3			
2 3 4			
5	282		287.88
6	42		47.88
7	54		59.88
8	42		47.88
9	64		69.88
10	577		582.88
11			
12	167		172.88
13	204		209.88
14		avg samp.	
15	32	183.9090	37.88
16	-14		-14
17	-11		-11
18	-40		-40
19	-2		-2
20	26		26
21	-38		-38
22	-22	avg ctrl.	-22
23		-5.88888	
24		std ctrl.	13
25	35	24.95972	35

			TEST 6	168 Hour	Humidity	7	
fuss#		Ro	Vmax			t(1/2)	Avg t1/2
	1	blown					-
	2	9.1		26.4	13.2	587	
	3				0		
	4	17.3			0		
	5	10.9		96	48	91	
	2 3 4 5 6 7	10.7		39.2	19.6	461	
	7	11		36	18	221	
	8	9.9		42.4	21.2	423	
	8 9	10.3		89.6	44.8	636	
	10	9.8		49.6	24.8	1222	
	11				0		
	12	10.6		18.4	9.2	339	
	13	10.2		39.2	19.6	687	
		blown			0		avg t1/2
	15	10		43.2	21.6	210	487.7
	16	9.5	52.8	52	26	183	
	17	9.4		88.8	44.4	395	
	18	9.3		51.2	25.6	254	
	19	8.7	73.6	72.8	36.4	401	
	20	9.2		85.6	42.8	403	
	21	9.3		56.8	28.4	225	
	22	9.2	44.8	44	22	219	avg ctrl.
	23				0		314.1111
	24	9.5		87.2	43.6		std.ctrl.
	25	9.6		94.4	47.2	402	87.21804

$\mathbf{T}$	est 6 D:	iff. from Test 1	
fuss #t		avg diff.	t-avg.dif.
1			
2 3 4	324		328.67
3			
4			
5	-268		-263.33
6	263		267.67
7	29		33.67
8	242		246.67
9	218		222.67
10	851		855.67
11			
12	24		28.67
13	541		545.67
14		avg samp.	
15	24	224.8	28.67
16	-27		-27
17	-19		-19
18	-21		-21
19	18		18
20	29		29
21	-52		-52
22	-16	avg ctrl.	-16
23		-4.66666	
24	18	std ctrl.	18
25	28	27.01439	28

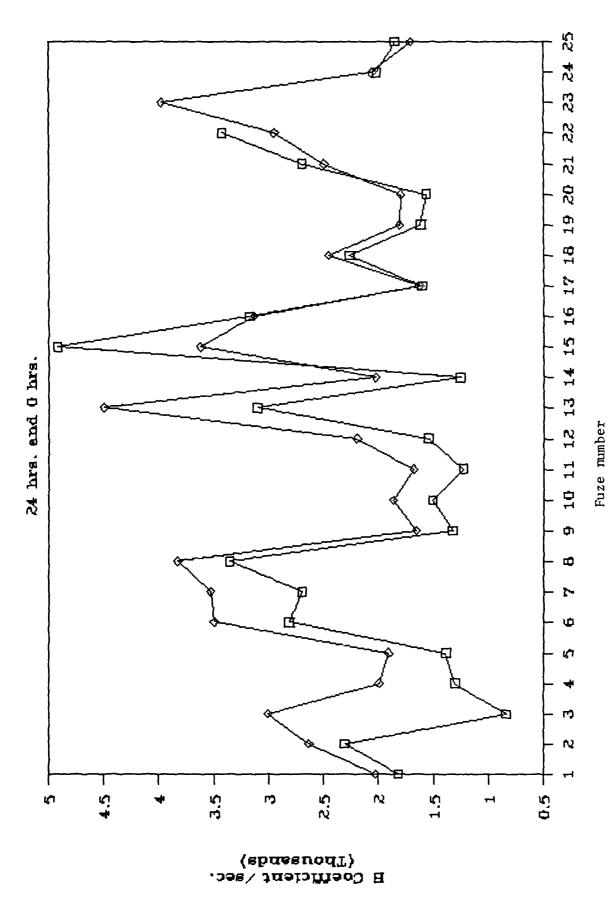
			TEST 7	192 Hours	Humidity	,	
fuss#		Ro	Vmax	V(t)	V(t)/2	t(1/2)	Avg t1/2
		blown			0		_
	2	8.9	28.8	27.2	13.6	390	
	3	Cut-up			0		
		Blown			0		
	5	10.9	120	113.6	56.8	637	
	б	10.9		44.8	22.4	266	
	7	11		39.2	19.6	227	
	8	9.9	43.2	41.6	20.8	244	
	9	10.4	107.2		52	493	
	10	10.1	75.2	65.6	32.8	914	
		Cut-up			0		
		Blown			0		
		10.7		40.8	20.4	209	
		blown			0		avg t1/2
	15	10.4		44	22		404.5555
	16	9.2	50.4	49.6	24.8	180	
	17	9.1		84	42	323	
	18	9		50.4	25.2	243	
	19	8.4		68	34	341	
	20	8.9		79.2	39.6	396	
	21	8.7		53.6	26.8	239	
	22	8.9		40.8	20.4	235	avg ctrl.
	23				0		300.7777
	24	9.2	85.6	84.8	42.4		std.ctrl.
	25	9.3		91.2	45.6	400	74.17363

fuss # t7-t1 avg diff. t7-t1-avg.ctrl.  1	Test 7 D	iff. from Test 1	
2 127 145 3 4 5 278 296 6 68 86 7 35 53 8 63 81 9 75 93 10 543 561 11		avg diff.	t7-t1-avg.ctrl.
4 5 278 296 6 68 86 7 35 53 8 63 81 9 75 93 10 543 561 11 12	1		
4 5 278 296 6 68 86 7 35 53 8 63 81 9 75 93 10 543 561 11 12	2 127		145
5       278       296         6       68       86         7       35       53         8       63       81         9       75       93         10       543       561         11       12	3		
6 68 86 7 35 53 8 63 81 9 75 93 10 543 561 11	4		
7 35 53 8 63 81 9 75 93 10 543 561 11	5 278		296
7 35 53 8 63 81 9 75 93 10 543 561 11	6 68		86
10 543 561 11 12	7 35		53
10 543 561 11 12	8 63		81
11 12	9 75		93
11 12	10 543		561
	12		
T) 0) OT	13 63		81
14 avg samp. avg. diff		avg samp.	avg. diff
15 75 147.4444 93 165.4444			
16 -30 -30			
17 -91 -91			
18 -32 -32			-32
19 -42 -42			
20 22 22			
21 -38 -38			
22 0 avg ctrl. 0		avg ctrl.	
23 -18			-
24 23 std ctrl. 23			23
25 26 36.79673 26			

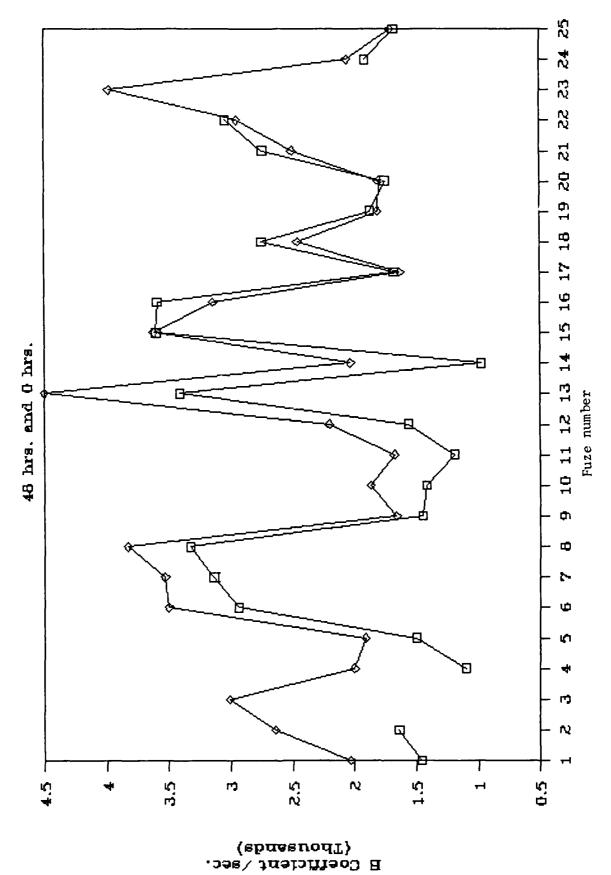
Appendix B

Coefficients and Graphs

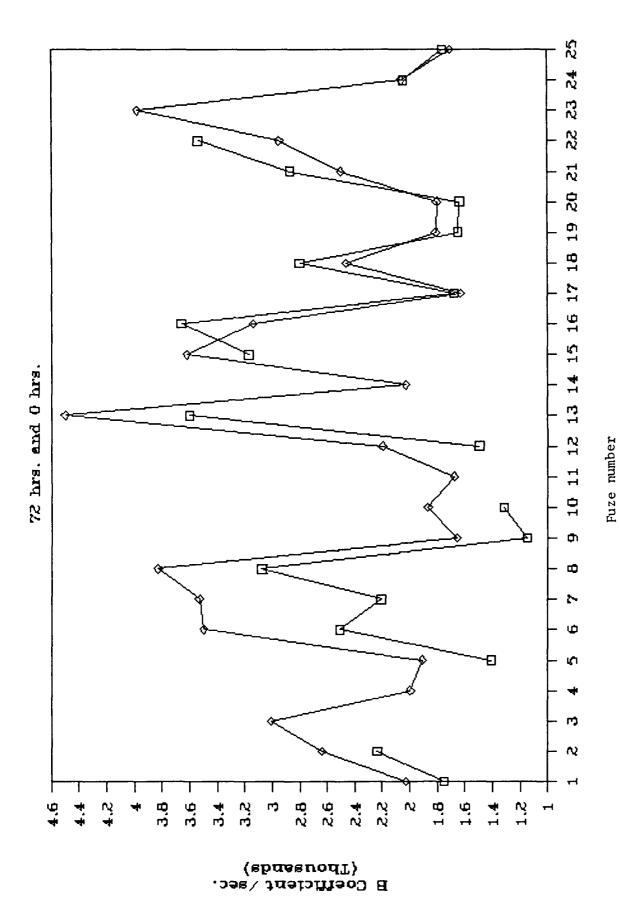
÷.	Co				oefficient			В		(/sec)					
fues#		192	hrs	168	hrs	96	hrs	72	hrs	48	hrs	24	hrs	0	hrs.
	1						1590		1750		1460		1820		2030
	2		1640		1180		906		2240		1640		2310		2640
	2 3												843		3010
											1100		1310		2000
	4 5 6 7		1000		7630		1020		1410		1500		1390		1910
	6		2600		1500		2890		2510		2940		2820		3500
			3050		3140		2820		2210		3140		2700		3530
	8 9		2690		1640		3110		3080		3330		3360		3830
	9		1350		1090		1410		1150		1450		1330		1660
	10		627		567		646		1320		1420		1510		1870
	11										1190		1230		1680
	12				2044		1390		1500		1560		1550		2200
	13		3320		1000		1927		3600		3410		3110		4500
	14										974		1260		2030
	15		2660		3300		3010		3170		3600		4920		3620
	16		3760		3790		3540		3660		3590		3180		3140
	17		2150		1755		1720		1680		1680		1610		1630
	18		2850		2730		2880		2800		2750		2270		2460
	19		2030		1730		1850		1650		1870		1620		1810
	20		1750		1720		1730		1640		1750		1570		1800
	21		2900		3080		2900		2870		2740		2700		2500
	2 <b>2</b>		2950		3170		3250		3540		3040		3430		2950
	23														3980
	24		1950		2010		2040		2050		1910		2020		2060
	25		1730		1720		1670		1760		1680		1850		1710



Graph B-1. Coefficient versus fuzes 1 through 25

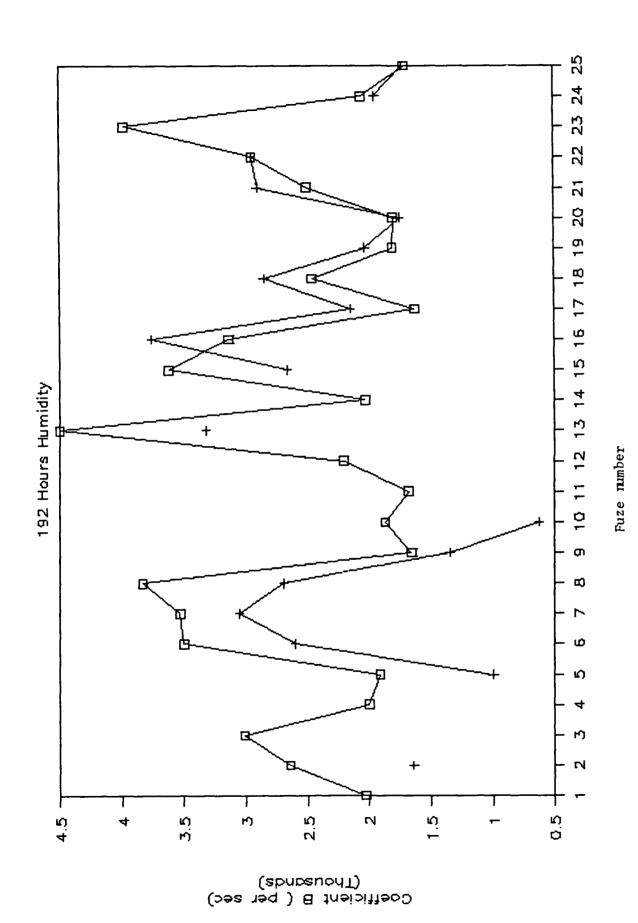


Graph B-2. Coefficient versus fuzes 1 thorugh 25



Graph B-3. Coefficient versus fuzes 1 through 25

Graph B-4. Coefficient versus fuzes 1 through 25



Graph B-5. Coefficient test 1 and test 7

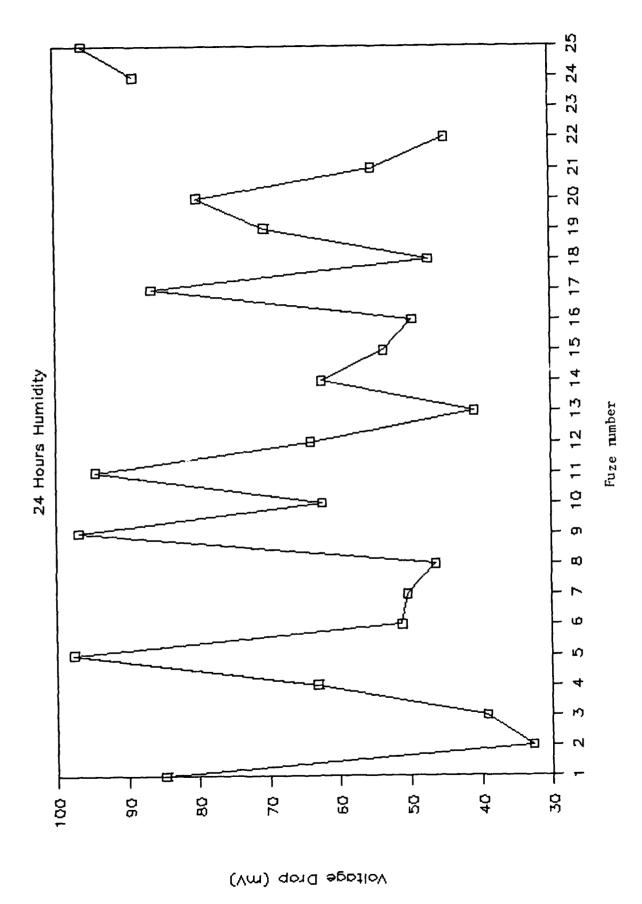
Graph B-6. Coefficient versus fuzes 1 through 25

B Coefficient /sec. (Thousands) Appendix C

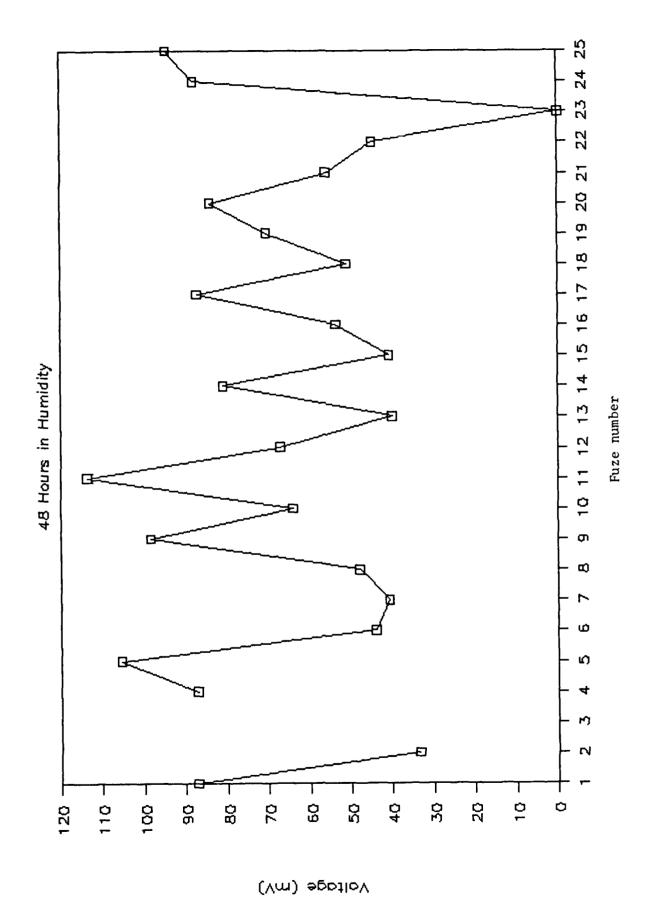
Graphical Data

Graph C-1. Maximum voltage drop versus fuzes 1 through 25

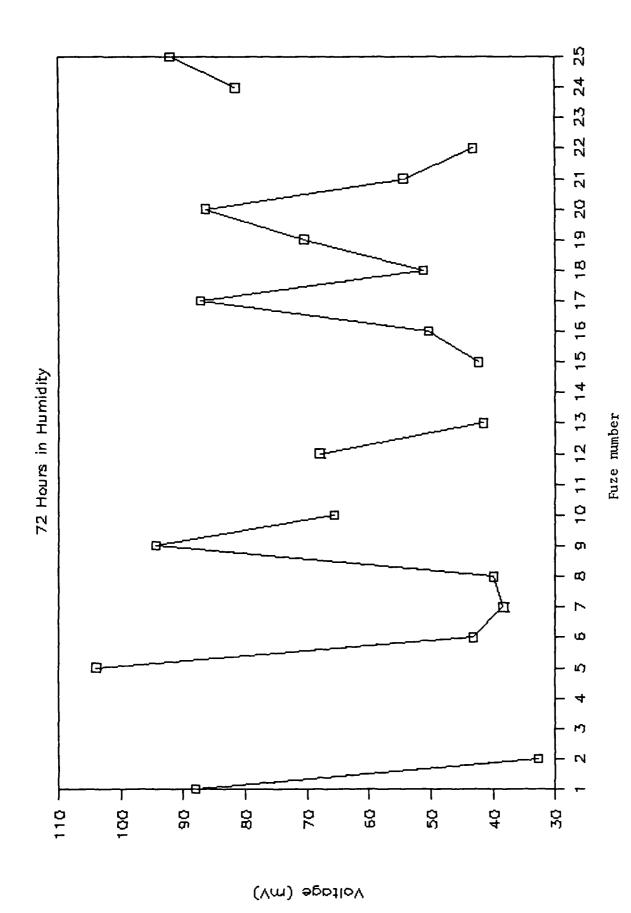
Maximum voltage Reached (mV)



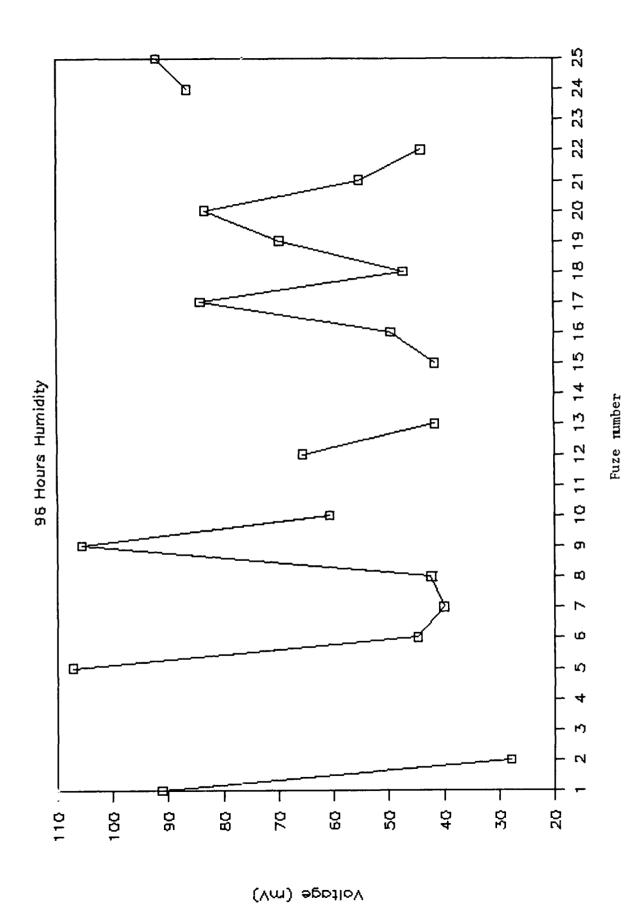
Graph C-2. Maximum voltage drop versus fuzes 1 through 25



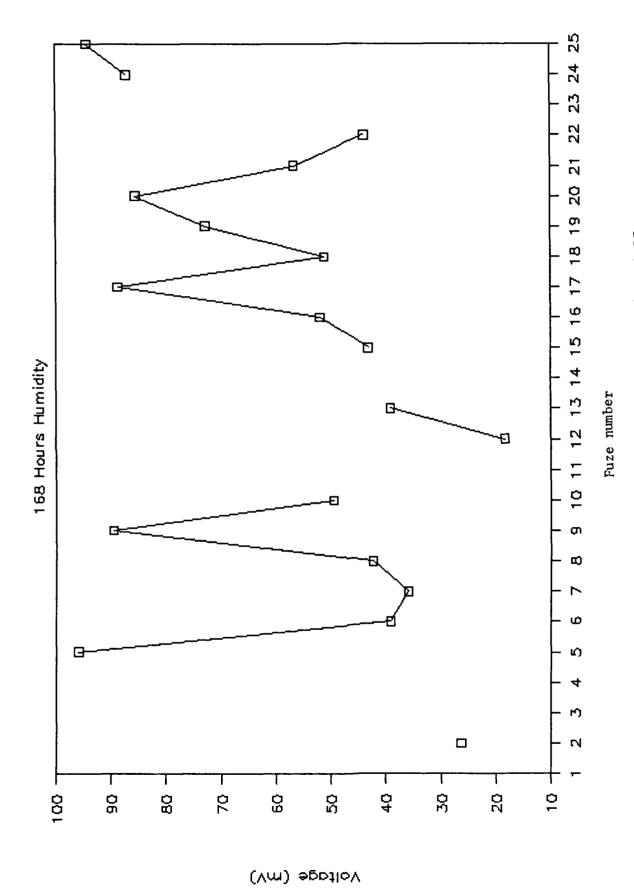
Graph C-3. Maximum voltage drop versus fuzes 1 through 25



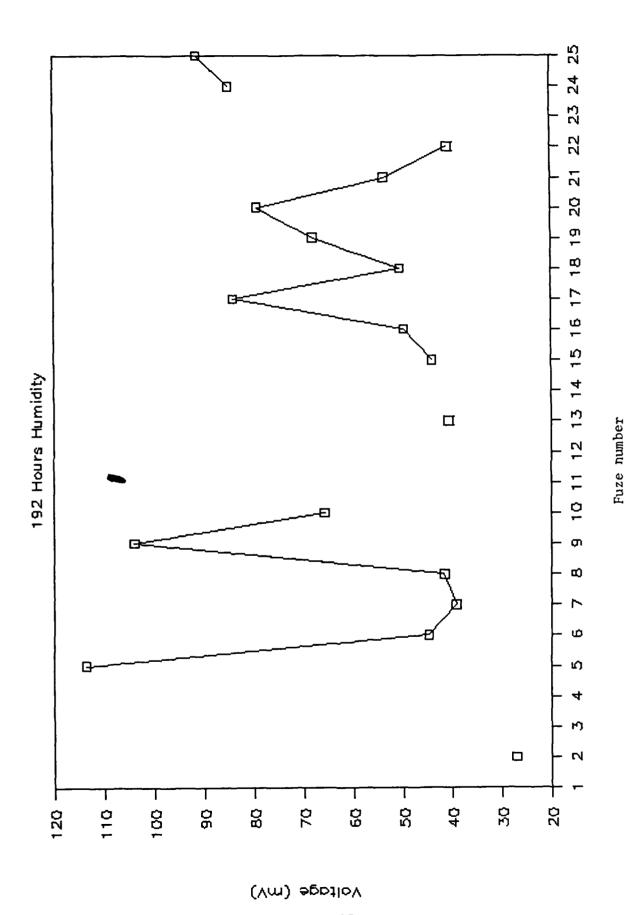
Graph C-4. Maximum voltage drop versus fuzes 1 through 25



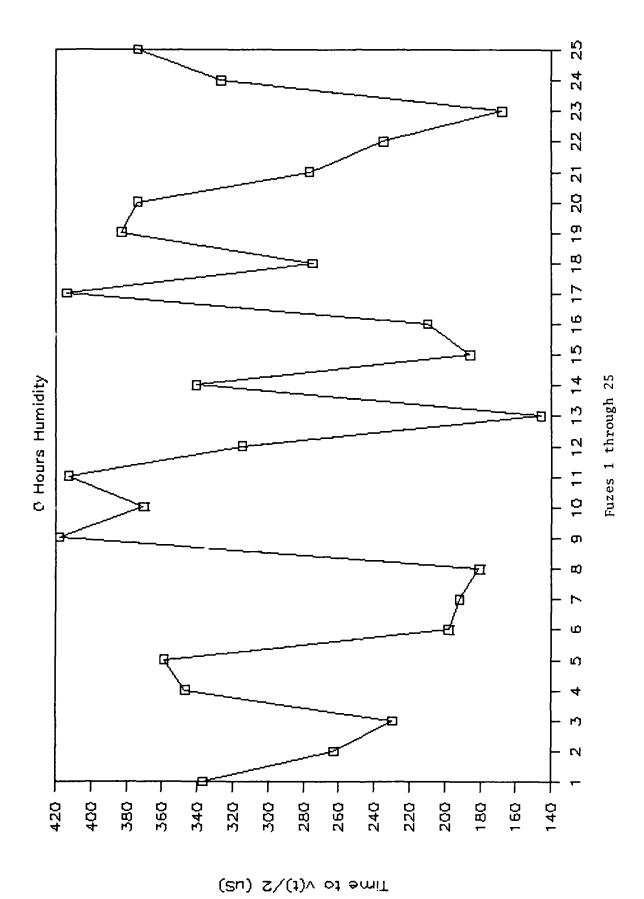
Graph C-5. Maximum voltage drop versus fuzes 1 through 25



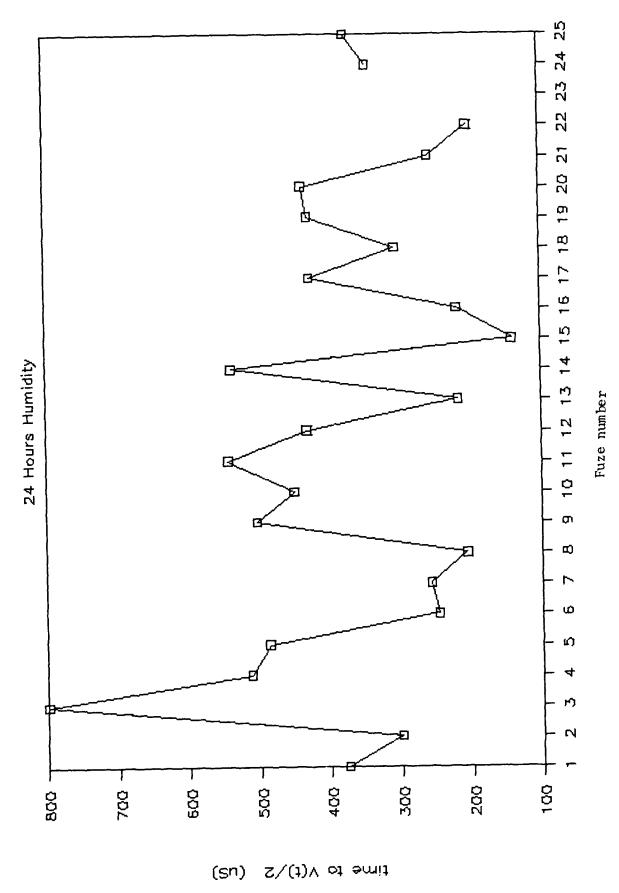
Graph C-6. Maximum voltage drop versus fuzes 1 through 25



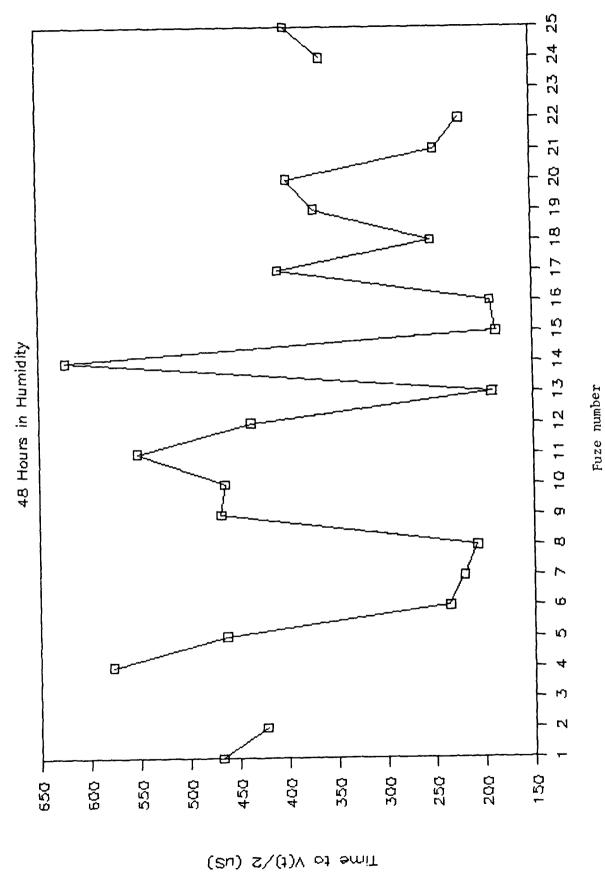
Graph C-7. Maximum voltage drop versus fuzes 1 through 25



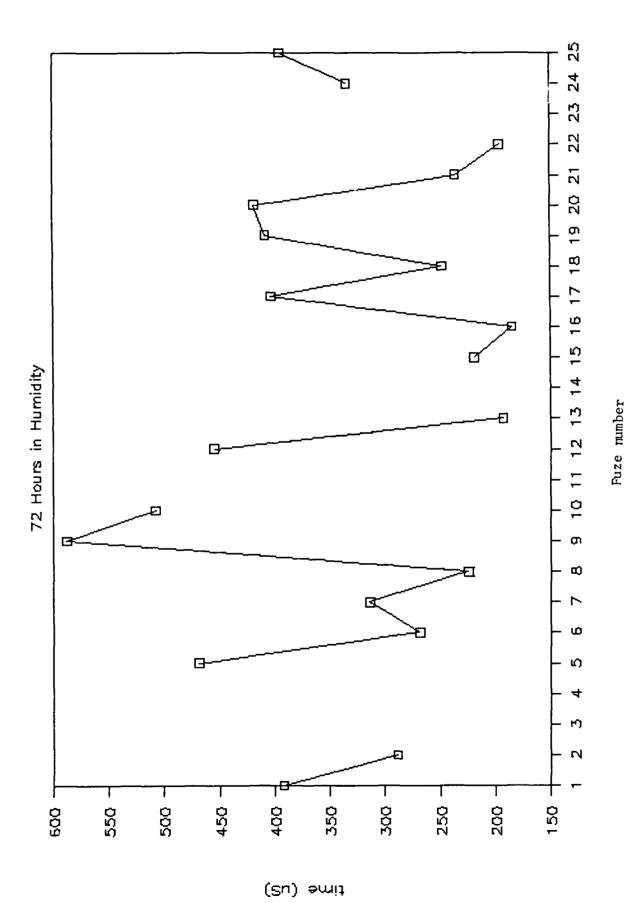
Graph C-8. Time to reach 1/2 Vmax



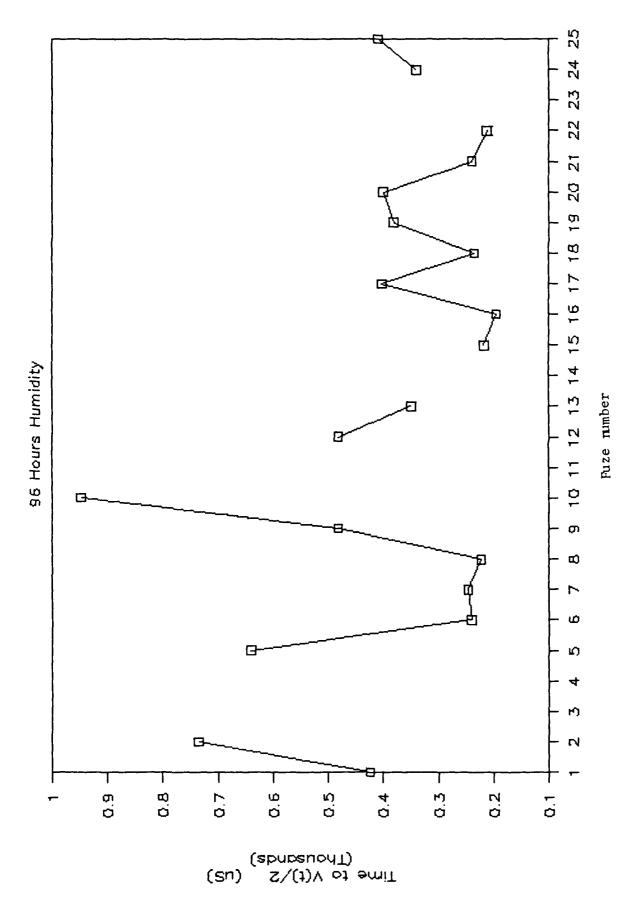
Graph C-9. Time to V(t)/2 versus fuzes 1 through 25



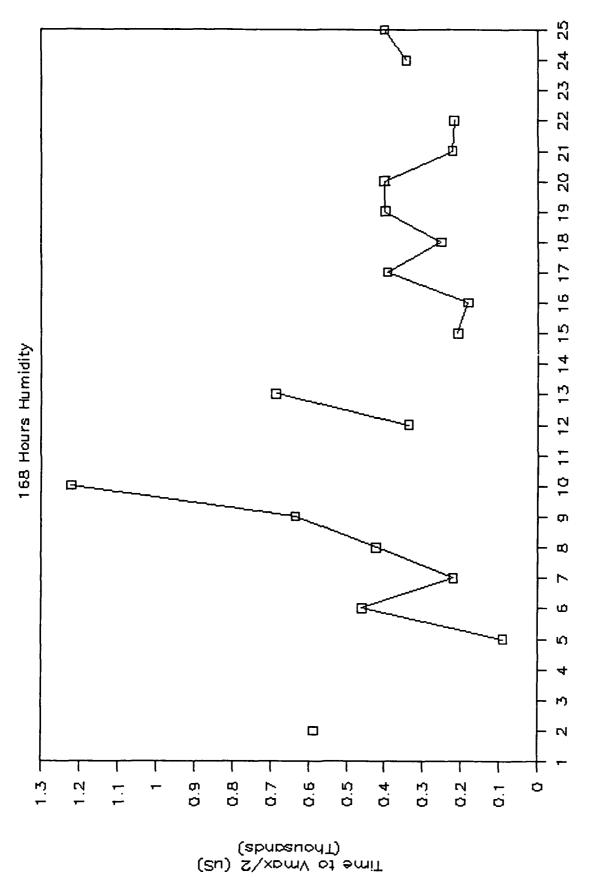
Graph C-10. Time to V(t)/2 versus fuzes 1 through 25



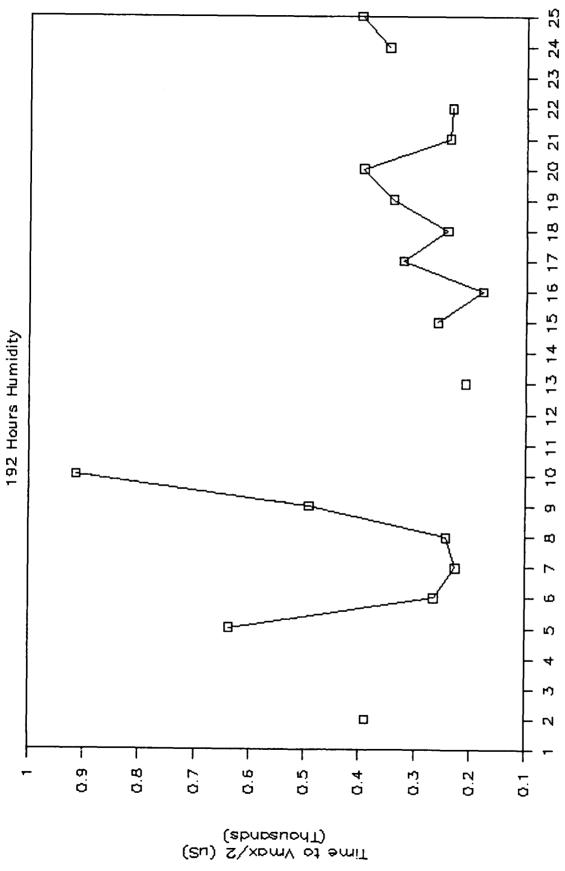
Graph C-11. Time to V(t)/2 versus fuzes 1 through 25



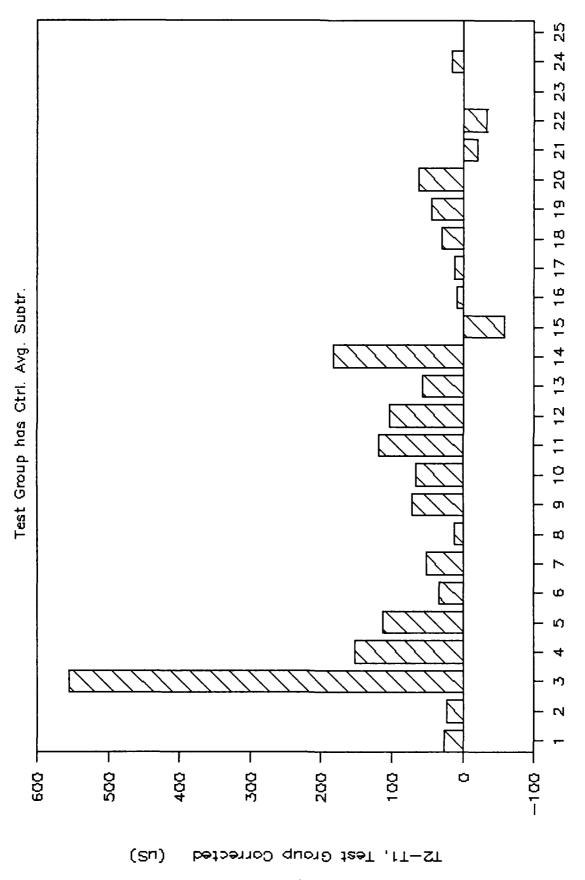
Graph C-12. Time to V(t)/2 versus fuzes 1 through 25



Graph C-13. Time to 1/2 Vmax versus fuzes 1 through 25



Graph C-14. Time to 1/2 Vmax versus fuzes 1 through 25

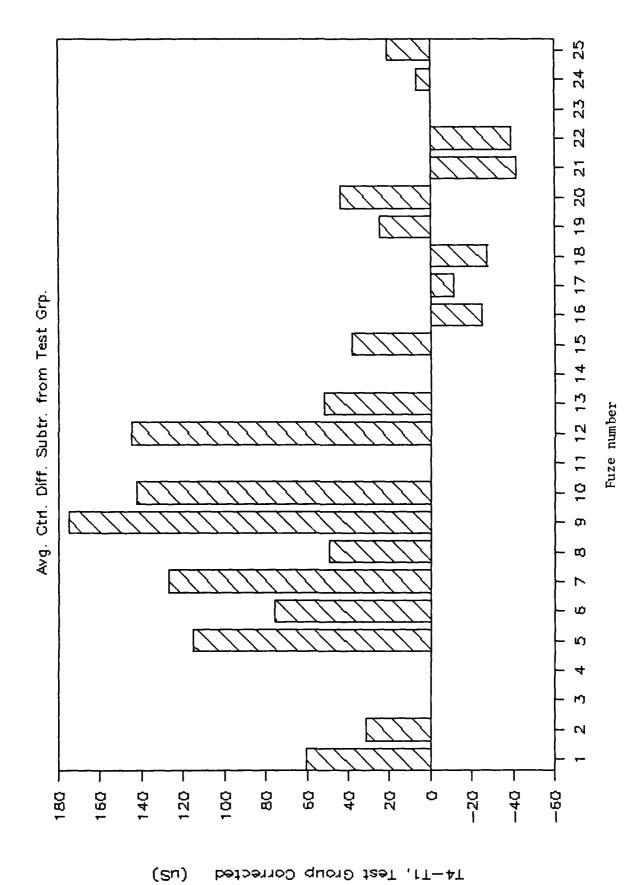


Graph C-15. T2 - T1 versus fuzes 1 through 25

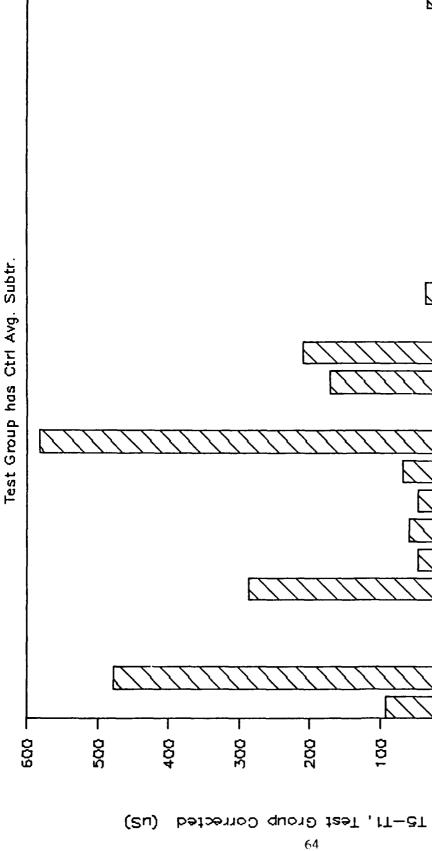
Graph C-16. T3 - T1 versus fuzes 1 through 25

T3-T1, Test Group Corrected

(Sn)



Graph C-17. T4 - T1 versus fuzes 1 through 25



Graph C-18. T5 - T1 versus fuzes 1 through 25

**B**)

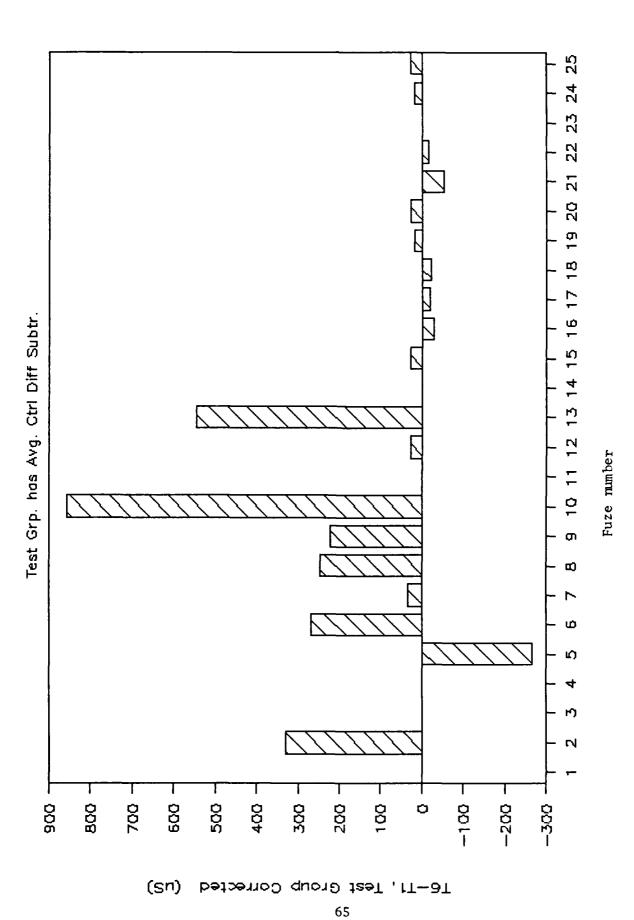
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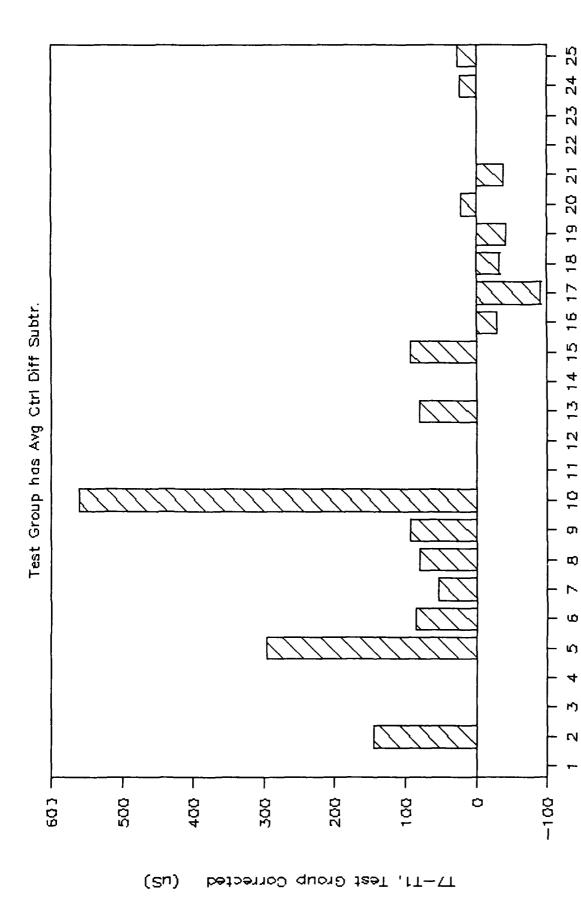
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Graph C-19. T6 - T1 versus fuzes 1 through 25



Graph C-20. T7 - T1 versus fuzes 1 through 25

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ATTN: AMXBR-OD-ST

Aberdeen Proving Ground, MD 21005-5066

## Chief

Benet Weapons Laboratory, CCAC Armament Research, Development and Engineering Center U.S. Army Armament, Munitions and Chemical Command ATTN: SMCAR-CCB-TL Watervliet, NY 12189-5000

# Commander

U.S. Army Armament, Munitions and Chemical Command ATTN: SMCAR-ESP-L Rock Island, IL 61299-6000

## Director

U.S. Army TRADOC Systems Analysis Activity ATTN: ATAA-SL White Sands Missile Range, NM 88002

## Director

Industrial Base Engineering Activity

ATTN: AMXIB-MT

Rock Island, IL 61299-5000